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# **Processing of 18% Ni Maraging Steel (350 Grade)**

**Army Materials and Mechanics  
Research Center**

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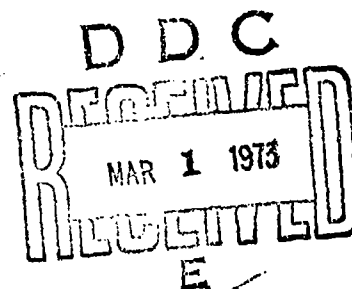
# PROCESSING OF 18% Ni MARAGING STEEL (350 GRADE)

ARMANDO A. IANNELLI  
MATERIALS APPLICATION DIVISION

September 1972

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ARMY MATERIALS AND MECHANICS RESEARCH CENTER  
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**PROCESSING OF 18% Ni MARAGING STEEL (350 GRADE)**

Product Technical Report by

**ARMANDO A. IANNELLI**

September 1972

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13. ABSTRACT This study was conducted to show effect of processing procedures on mechanical properties of 18% nickel (350 grade) maraging steel. The material was subjected to variable forging, solution treatments and aging temperatures. Air melt versus vacuum melt comparisons are shown. (Author)			

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## INTRODUCTION

### Background

Research in the past ten years<sup>1</sup> has resulted in strength increases of approximately 50% on 18% Ni maraging steel. This resulted primarily with increases in cobalt and titanium content.

In addition to its high strength, 18% Ni maraging steel has good hot- and cold-forming characteristics, is easily welded, and exhibits minimum distortion during heat treatment.

In previous work<sup>2</sup> segregation has been known to occur. Alloy content, fabrication, heat treatment, and element interaction have been contributing factors. Higher cobalt and reduction of molybdenum and titanium have decreased segregation, while homogenization and hot working have been beneficial. Molybdenum and titanium are believed to segregate during solidification. Hot working will alleviate segregation effect while overaging may be detrimental.

Tuffnell and Cairns<sup>3</sup> have investigated the effect of composition on tensile strength on 18% Ni (350 grade) maraging steel. Their work was conducted with specimens from a 5000-lb heat, which was described as semi-commercial. They achieved tensile strength of 352 ksi with 12 ft-lb Charpy V-notch impact energy from 1-inch bars and 338 ksi with 5 ft-lb impact energy from transverse specimens from a 5-inch billet.

Variables in hot rolling of 18% Ni (250 grade) maraging steel have been studied.<sup>4</sup> Effect on fracture toughness was determined for 1/2-inch plate rolled with finishing temperatures in the range of 1600 F to 1980 F. Cooling rates were also varied. It was determined that  $K_{IC}$  could be increased with higher cooling rates.

Continuing research and development are eliminating some of the problems and, as indicated in Reference 5, maraging steel is tougher than most of the more common ultrahigh strength steels and is being used in aerospace design.

### Object

The object of this study was to obtain data for possible use of 350 grade 18% Ni maraging steel in Army materiel. The study included effects of air melt

<sup>1</sup>HAMAKER, J. C., and BAYER, A. M. *Applications of Maraging Steels*. Cobalt, no. 38, March 1968.

<sup>2</sup>SALMON, P. H., et al. *The Origin and Significance of Banding in 18% Ni (250) Maraging Steel*. Trans. AIME, v. 239, November 1967, p. 1809.

<sup>3</sup>TUFFNELL, G. W., and CAIRNS, R. L. *18% Nickel 350 - Maraging Steel*. Trans. ASM, v. 61, 1968, p. 798-806.

<sup>4</sup>SPEEDER, G. J., BROWN, R. M., and MURPHY, W. J. *The Effect of Hot Rolling Variables on the Fracture Toughness of 18% Ni Maraging Steel*. Trans. ASM, v. 60, 1967, p. 418-425.

<sup>5</sup>IMRIE, W. M. *Maraging Steel in the British Aerospace Industry*. Metal Forming, v. 37, no. 1 and no. 2, January and February 1970.



versus vacuum melt, forging temperature, solution and aging temperatures, and test temperatures on mechanical properties. Microstructures at various stages of processing are shown.

## Scope

Mechanical properties were obtained for: forging temperatures of 1900, 2100, and 2300 F; solution temperatures of 1450, 1500, and 1550 F; aging temperatures of 900, 950, and 1000 F; and test temperatures from -110 F to +200 F.

## MATERIAL

The chemical analysis of the material for the bulk of this work was:

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Ni</u>	<u>Mo</u>	<u>Co</u>	<u>Ti</u>	<u>Al</u>	<u>P</u>	<u>S</u>
0.02	0.018	0.02	18.20	4.70	11.17	1.53	0.084	0.004	0.004

This material was consumable - arc vacuum melted, and was purchased in 3-inch bar stock form, which was produced commercially.

Two billets were provided for air versus vacuum melt comparisons. The material was induction melted and cast at the Army Materials and Mechanics Research Center in 40-lb ingots. The chemical analysis taken by X-ray fluorescence spectroscopy was:

<u>Air Melt (H637)</u>				<u>Vacuum Melt (H636)</u>			
<u>Ni</u>	<u>Co</u>	<u>Mo</u>	<u>Ti</u>	<u>Ni</u>	<u>Co</u>	<u>Mo</u>	<u>Ti</u>
18.1	10.8	4.6	1.1	18.1	10.6	4.6	1.5

## SPECIMEN PREPARATION

Specimens were taken in a longitudinal direction in all cases except one. Transverse tension and Charpy specimens were taken from the commercial bar stock. All specimens were 0.252-inch tensiles and 0.394-inch V-notched Charpy bars.

Thirty tension and 30 Charpy specimens were taken from the "as-received" 3-inch-diameter bar stock. Groups of nine were subjected to solution temperatures of 1450, 1500, and 1550 F for 1 hour followed by air cooling. Three samples from each group were aged at 900, 950, and 1000 F for 3 hours followed by air cooling, and subsequently tested at -110, 68, and 200 F.

Three tension and 3 Charpy specimens were taken from the "as-received" 3-inch-diameter bar in a transverse direction. They were heat treated to 1500 F for 1 hour, air cooled; and aged at 900 F for 3 hours, air cooled. They were subsequently tested at -110, 68, and 200 F.

Thirty-six tension and 36 Charpy specimens were taken from forged and heat-treated 3/4-inch-diameter rods. Three groups of 12 were subjected to forging temperatures of 1900, 2100, and 2300 F. Each group of 12 was subjected to three

solution temperatures of 1450, 1500, and 1550 F and subsequently aged at 850, 900, 950, and 1000 F. All tension specimens of this series were tested at room temperature. The Charpy specimens were tested at -40 F.

Six tension and 6 Charpy specimens were taken from the as-forged 3/4-inch-diameter rods. Two samples were taken from each of three rods, which were forged at 1900, 2100, and 2300 F. Tension testing was conducted at room temperature, and Charpy tests at -40 F.

Two tension and 2 Charpy samples were taken from each of two 3/4-inch-diameter rods which were forged from air-melted and vacuum-induction-melted billets. The forging temperature was 2100 F in both cases. Subsequent heat treatment was 1500 F for 1 hour, air cooled; 900 F for 3 hours, air cooled. Tension testing was conducted at room temperature and Charpy impact energy tests were conducted at -40 F.

Specimen preparation data is shown in Table I.

Table I. SPECIMEN PREPARATION

Origin of Specimens		Temp (deg F)		
		Forging	Solution	Aging
3-inch-diam. Bar Longitudinal		-	1450, 1500, 1550 1 hr-AC	900, 950, 1000 3 hr-AC
3-inch-diam. Bar Transverse		-	1500-1 hr-AC	900-3 hr-AC
Forged & Heat Treated 3/4-inch-diam. Rod		1900 2100 2300	1450 1500 1550 } 1 hr-AC	850, 900, 950, 1000 3 hr-AC
As Forged 3/4-inch-diam. Rod		1900 2100 2300		
Forged & Heat Treated 3/4-inch-diam. Rod	Air Melt	2100	1500-1 hr-AC	900-3 hr-AC
	Vacuum Melt			

## RESULTS

Figure 1 shows mechanical properties of 18% Ni maraging steel forged at 1900 F as aging temperature is varied from 850 F to 1000 F. These data are evolved from solution temperatures of 1450, 1500, and 1550 F.

Figure 1a reveals tensile strength highest at aging temperature of 1000 F, with corresponding Charpy V-notch impact energy being minimum (9 ft-lb), within aging temperature range of 850 F to 1000 F. Large differences between yield strength and tensile strength appear to be a direct result of the 1450 F solution temperature.

Figure 1b indicates highest tensile strength at aging temperature of 950 F with tensile strength at 1000 F being approximately the same (360 ksi) as indicated in Figure 1a, but Charpy V-notch impact 33% less (6 ft-lb).

Figure 1c reveals maximum tensile strength of 350 ksi at 1000 F aging temperature with Charpy V-notch energy again at 33% less (6 ft-lb) than the data of Figure 1a.

With the high strength data observed, one would conclude optimum solution temperature to be 1450 F, and optimum aging temperature to be 1000 F.

Figure 2 shows similar data for a forging temperature of 2100 F. The highest tensile strength in this series is observed in Figure 2b at 1500 F solution temperature with aging at 1000 F. As indicated in Figure 1a, a large difference occurs between yield strength and tensile strength at solution temperature of 1450 F.

In Figure 3, results of a similar series of tests show mechanical properties at a forging temperature of 2300 F. Data trends are the same as the two previous series indicating the large range of forging temperatures with which this material can be formed. The highest tensile strength, 375 ksi, is observed after solution temperature of 1550 F, and aging temperature of 950 F.

Figure 4 shows tensile properties of specimens taken from 3-inch-diameter bar stock. These data were generated to show effect of test temperature and size reduction on tensile properties.

An increase of approximately 5% in tensile strength was noted when material was forged from 3 inches in diameter to 5/8 inch diameter. Transverse data (Figure 4b) at room temperature of the 3-inch-diameter bar shows a decrease of 50 to 60% in reduction of area and elongation, although the transverse tensile strength was equal to that of the longitudinal strength. This has been observed previously by W. M. Imrie,<sup>5</sup> who concluded that double vacuum melting may be the answer to higher ductility.

At low test temperatures, (-110 F), tensile strength is highest, (380 ksi) and elongation and reduction of area are slightly lower. Charpy values are considerably lower (40 to 60%). Comparison of longitudinal and transverse Charpy V-notch tests indicate 40 to 60% lower impact energy above 68 F but equal at -110 F.

The effect of forging temperature on mechanical properties is shown in Figure 5. A 5 to 11% increase in strength is noted as forging temperature increases from 1900 F to 2100 F, at which point higher forging temperatures have little effect. Ductility is high, as would be expected from as-forged material, with negligible forging temperature effect.

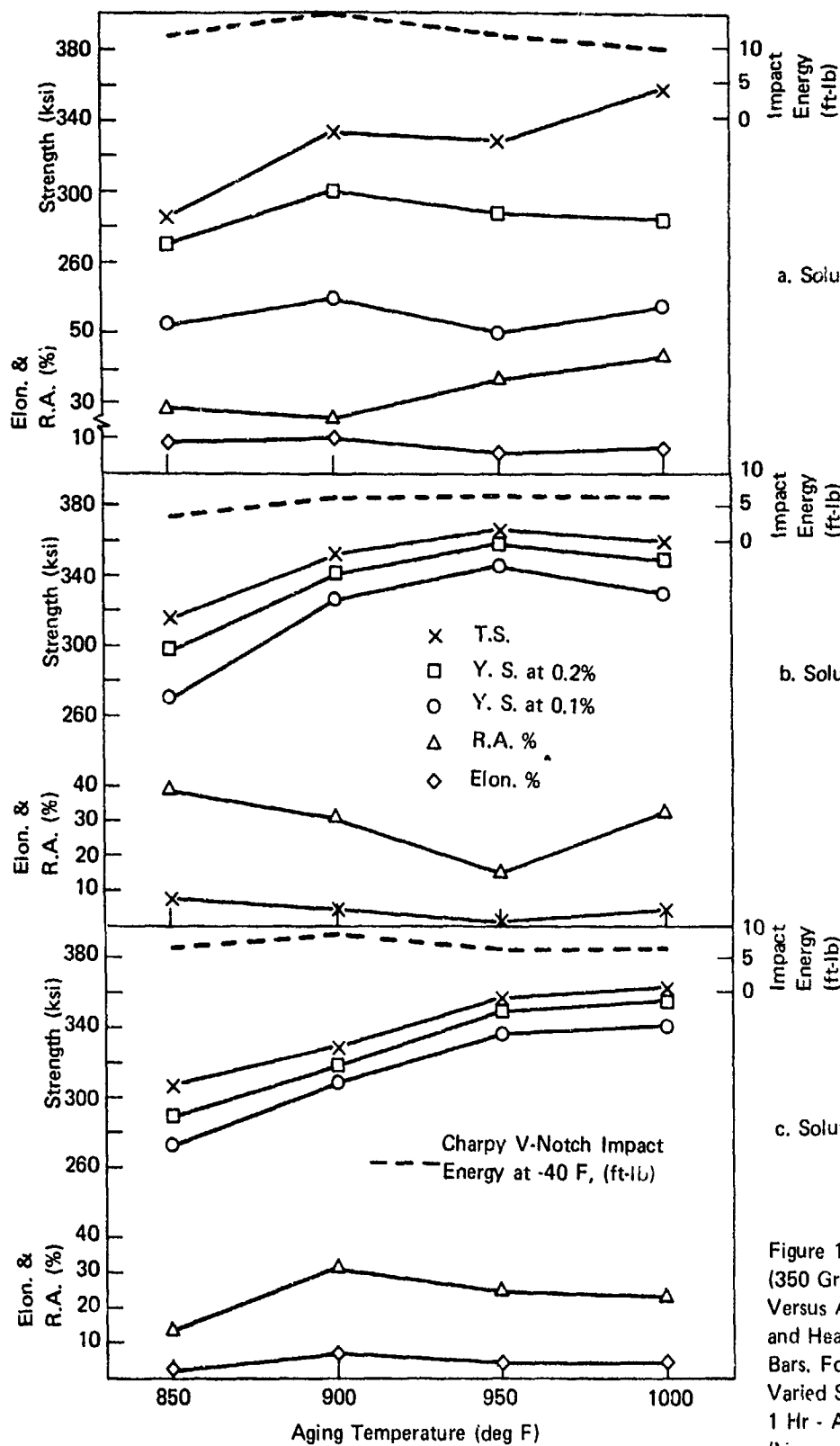


Figure 1. 18% Ni Maraging Steel (350 Grade) Mechanical Properties Versus Aging Temperature. Forged and Heat-Treated 3/4-Inch-Diameter Bars. Forging Temperature 1900 F. Varied Solution Temperatures - 1 Hr - A.C.; Aged 3 Hr - A.C. (Vacuum Melted)

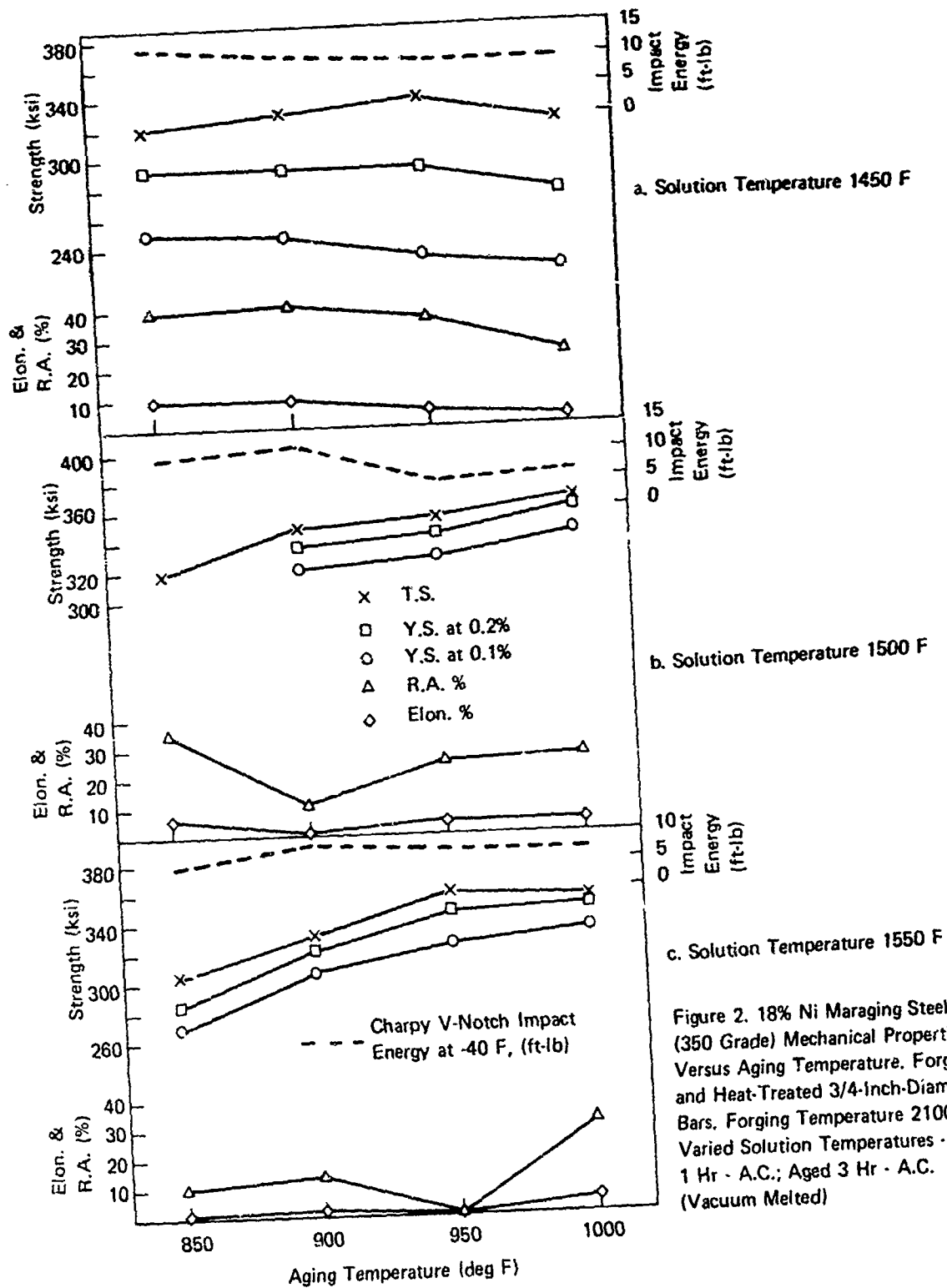


Figure 2. 18% Ni Maraging Steel (350 Grade) Mechanical Properties Versus Aging Temperature. Forged and Heat-Treated 3/4-Inch-Diameter Bars, Forging Temperature 2100 F. Varied Solution Temperatures - 1 Hr - A.C.; Aged 3 Hr - A.C. (Vacuum Melted)

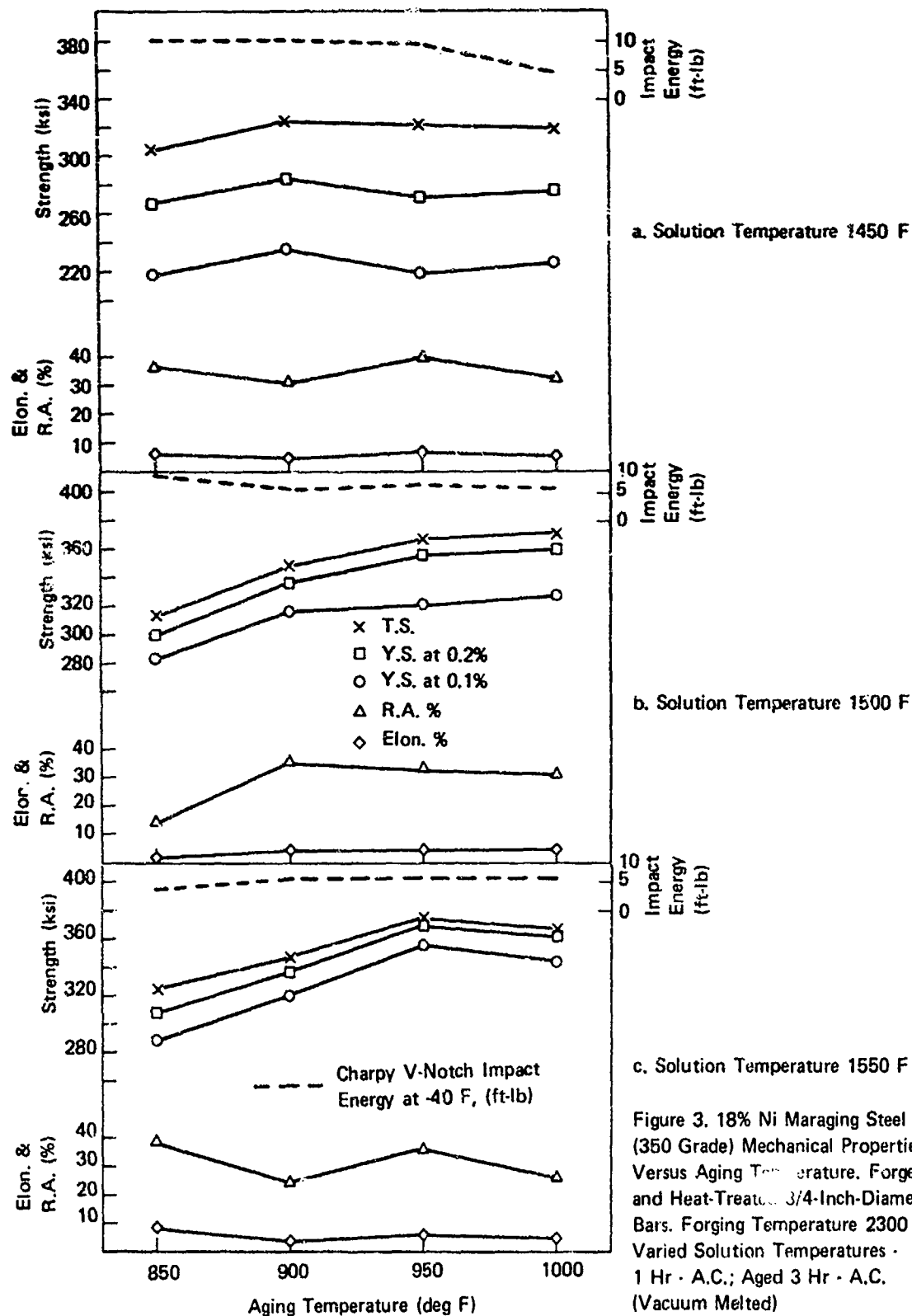
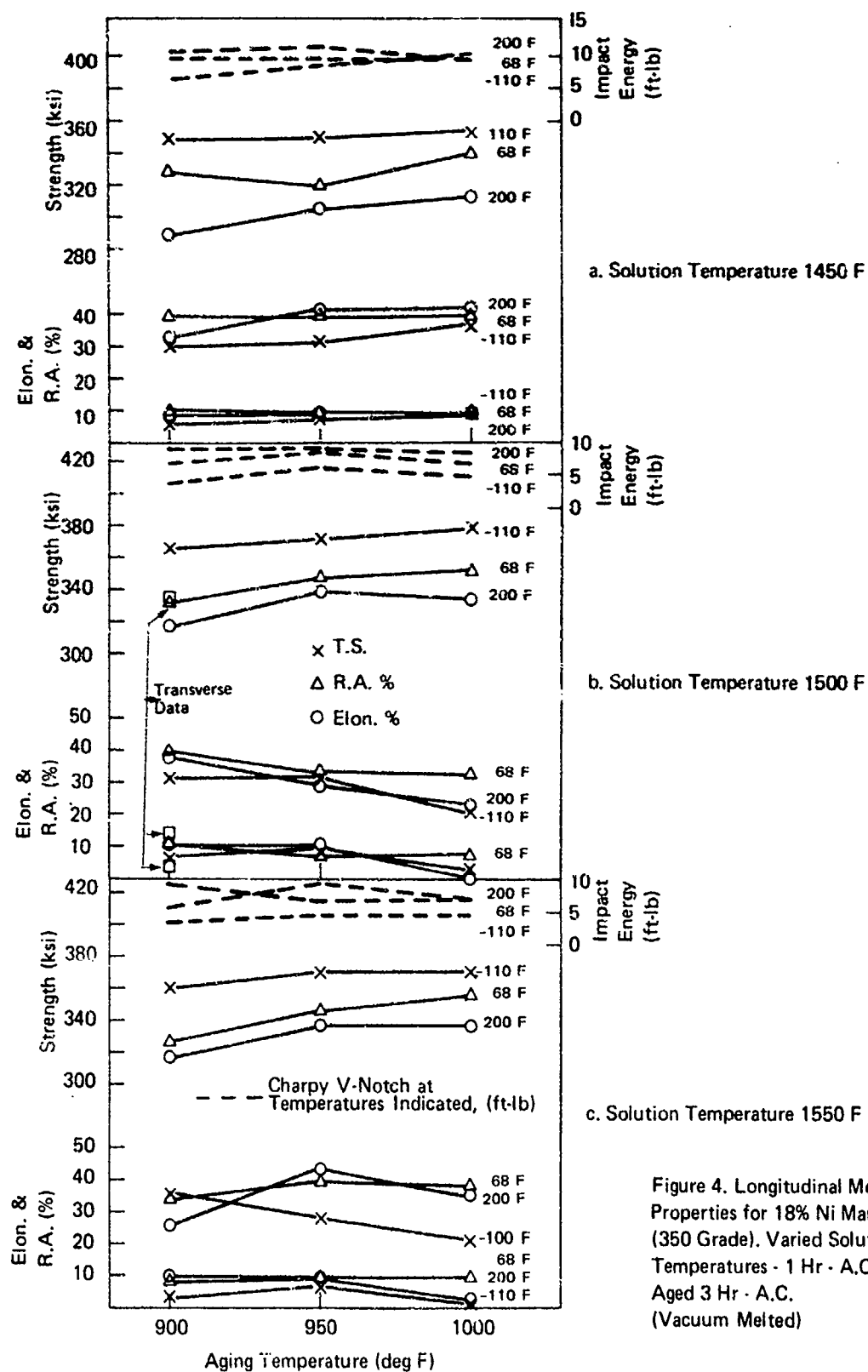


Figure 3. 18% Ni Maraging Steel (350 Grade) Mechanical Properties Versus Aging Temperature. Forged and Heat-Treated 3/4-Inch-Diameter Bars. Forging Temperature 2300 F. Varied Solution Temperatures - 1 Hr - A.C.; Aged 3 Hr - A.C. (Vacuum Melted)



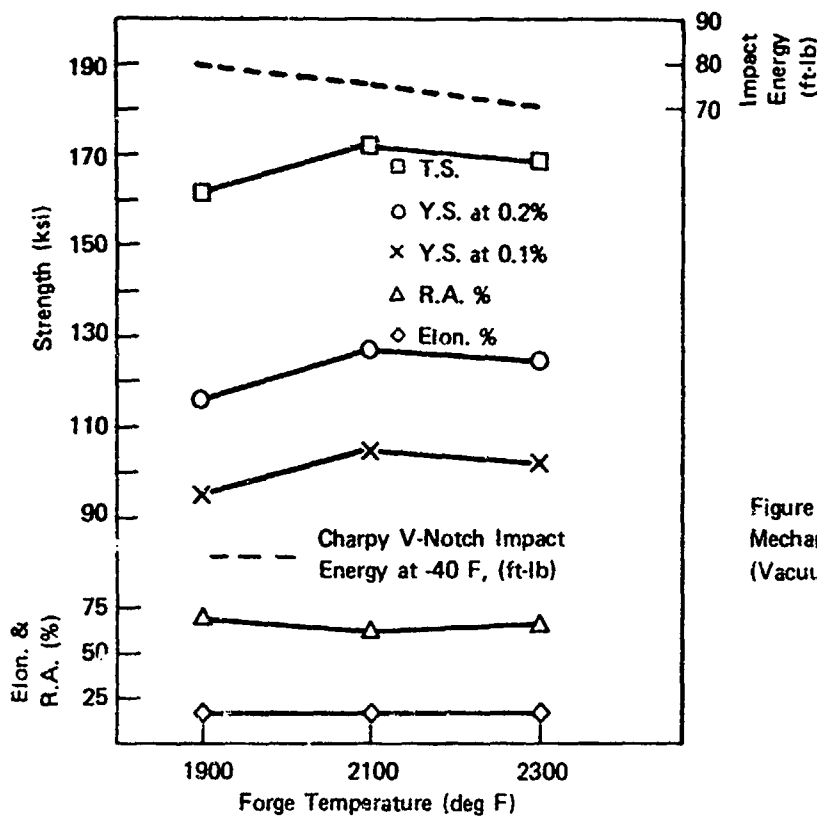


Figure 5. Forging Temperature Versus Mechanical Properties - As Forged Rods (Vacuum Melted)

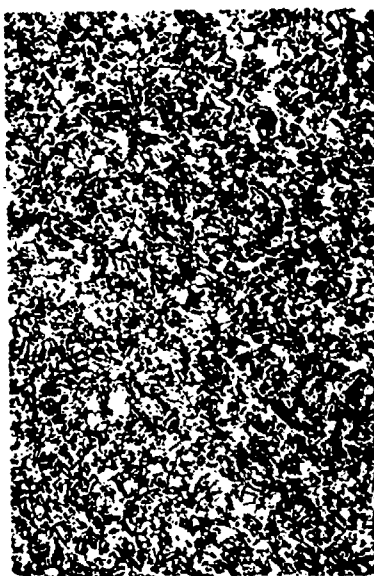
Figure 6 shows microstructures at 100X of vacuum-melted 18% Ni maraging steel forged at 1900, 2100, and 2300 F. Forging at 1900 F and 2300 F produces the same grain size, while that of the intermediate forging temperature of 2100 F shows larger grains. This may account for the higher tensile strength (Figure 5). The larger grains produced at forging temperature of 2100 F are inconsistent with expected results and should be investigated further.

Figures 7 and 8 show microstructures at 100X of air melt and vacuum melt, in the as-cast and forged conditions. Except for well-defined grain boundaries in the vacuum-melted case, no significant differences are observed in air versus vacuum melt for either the as-cast or forged material.

Microstructures of 18% Ni maraging steel after forging and heat treating are shown in Figure 9a of an air melt and Figure 9b of a vacuum melt. No appreciable differences are noted except that the air-melted structure is finer grained. The difference in grain size is attributed to casting method and not the subsequent working or heat treatment. A comparison of air melt, as cast (Figure 7a), with vacuum melt, as cast (Figure 8a), verify this observation.

Table II shows comparisons of air melt versus vacuum melt casting. Although tensile strength is greater for the vacuum-melted steel, the ductility is markedly less.

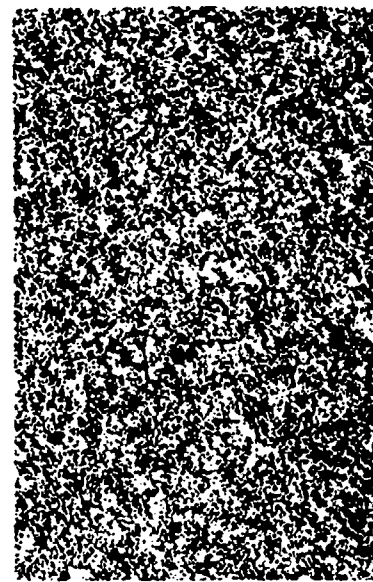




a. 1900 F

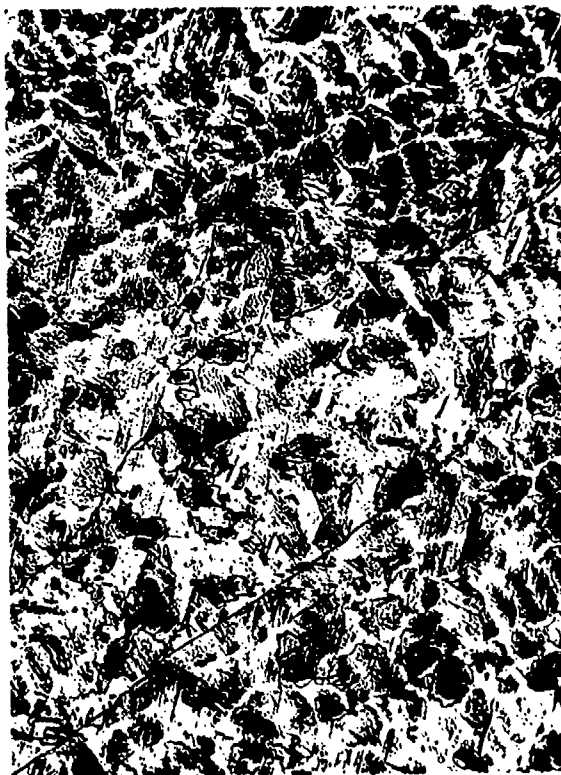


b. 2100 F

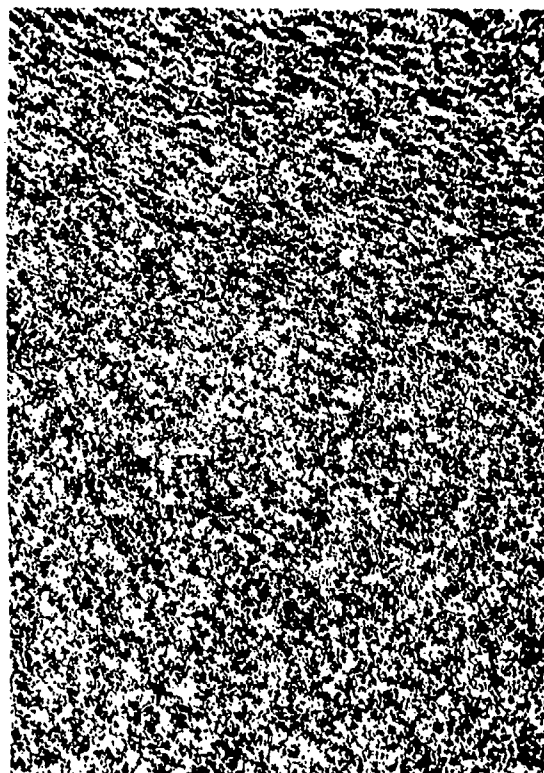


c. 2300 F

Figure 6. 18% Ni Maraging Steel, Vacuum Melt (Commercial) Forged

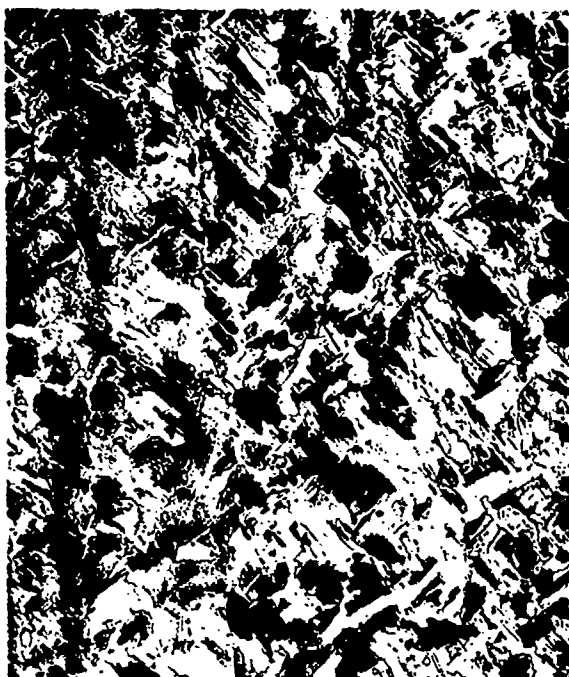


a. As Cast



b. Forged at 2100 F

Figure 7. 18% Ni Maraging Steel Air Melted (AMMRC)



a. As Cast

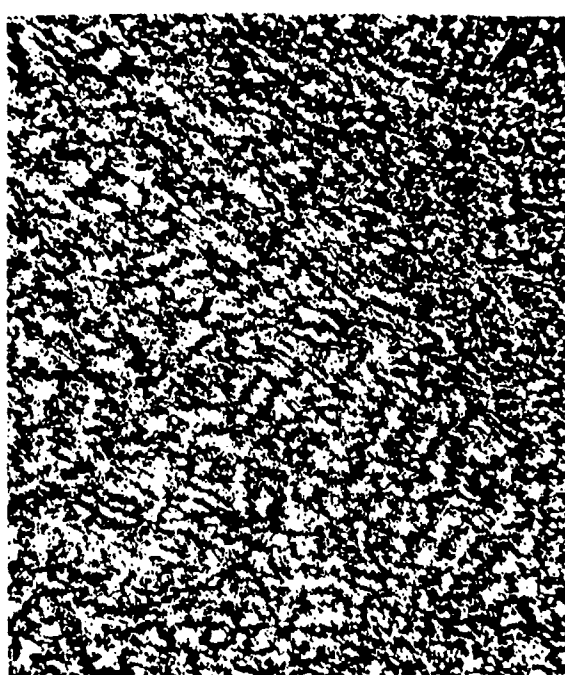


b. Forged at 2100 F

Figure 8. 18% Ni Maraging Steel Vacuum Melted (AMMRC)



a. Air Melt (AMMRC)



b. Vacuum Melt

Figure 9. 18% Ni Maraging Steel, Forged at 2100 F;  
Heat Treatment: 1500 · 1 Hr · AC, 900 · 3 Hr · AC

(AMMRC)

Table II. MECHANICAL PROPERTIES 18% Ni MARAGING STEEL (350 GRADE)  
Air melt versus vacuum melt 3-inch-diameter billets -  
forged to 3/4 inch diameter at 2100 F, heat treatment  
1500 F-1 hr-AC, aged 900 F-3hr-AC.

	YS at 0.1% (ksi)	YS at 0.2% (ksi)	TS (ksi)	Elong. (%)	RA (%)	Charpy V-Notch Impact Energy at -40 F (ft-lb)
Air Melt	292	308	320	8	38	10
Vacuum Melt	299	316	329	6	24	7

#### RECOMMENDATION

Further investigation of air melt versus vacuum melt 18% maraging steel should be pursued. Additional study should include toughness, thermal stability, and processing evaluations.

#### CONCLUSIONS

1. After normal working and heat treatment, air-melted 18% Ni maraging steel (as compared to vacuum melted) was slightly lower in tensile strength and 30 to 50% higher in ductility as measured in the longitudinal direction. The reverse is true for ductility in the transverse direction.
2. The differences in tensile properties between forging at 2000 F and 2300 F were negligible.
3. Aging temperatures between 900 F and 950 F produced optimum properties. However, if high tensile strength is of prime importance, aging at 950 F to 1000 F with 1500 F to 1550 F solution temperature should be considered.